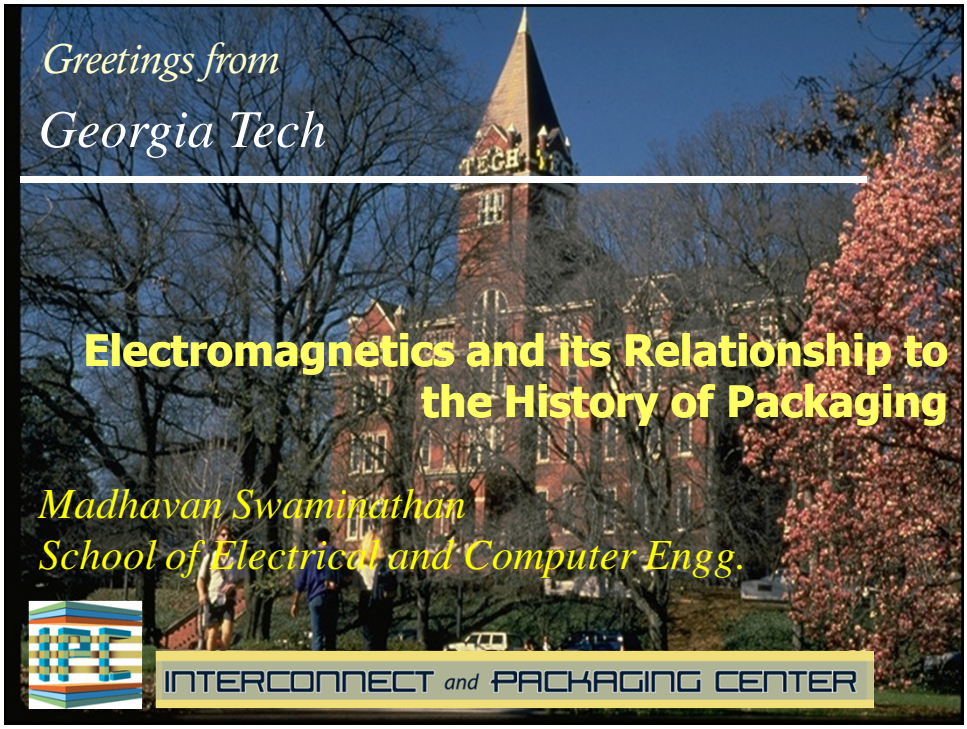
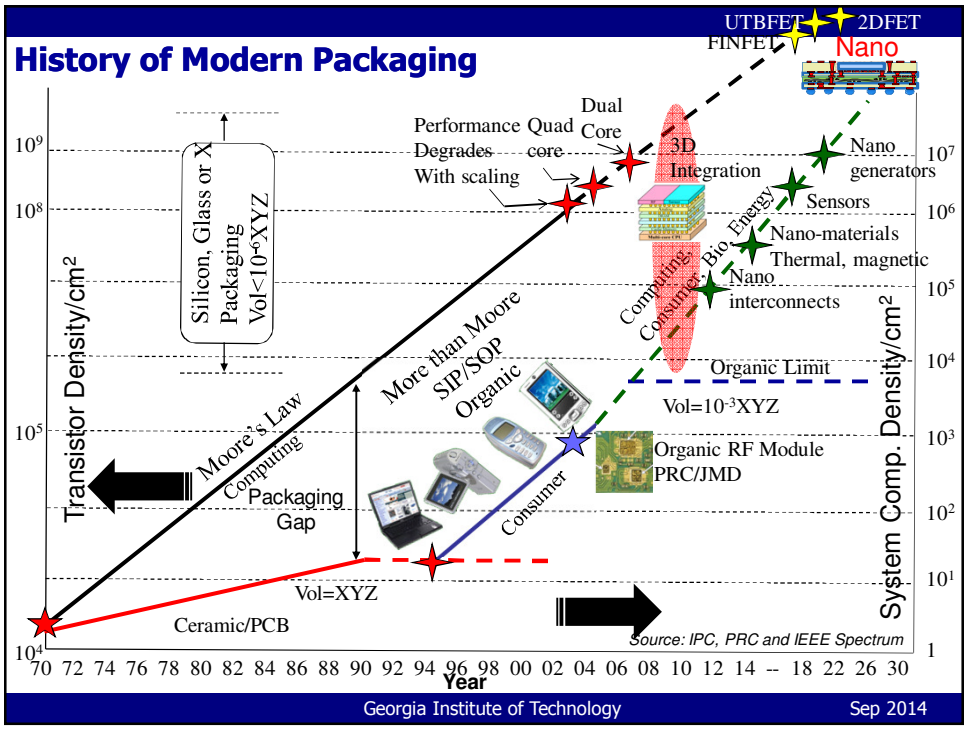
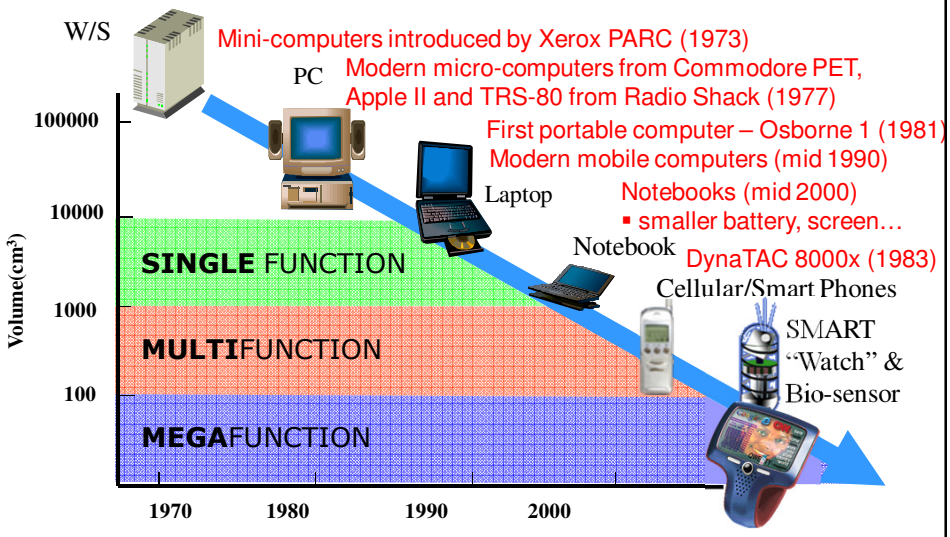

Greetings from
Georgia Tech
Electromagnetics and its Relationship to the History of Packaging
Madhavan Swaminathan
School of Electrical and Computer Engg.
INTERCONNECT and PACKAGING CENTER


History of Modern Packaging
UTBFET
2DFET
FINFET
Nano
Performance Degrades With scaling
Quad core
Dual Core
3D Integration
Nano generators
Sensors
Nano-materials
Thermal, magnetic
Nano interconnects
Bio Energy
Computing
Consumer
Silicon, Glass or X
Packaging Vol<10⁻⁶XYZ
More than Moore
SIP/SOP
Organic
Moore's Law
Computing
Packaging Gap
Consumer
Organic Limit
Vol=10⁻³XYZ
Organic RF Module
PRC/JMD
Vol=XYZ
Ceramic/PCB
Transistor Density/cm²
System Comp. Density/cm²
Year
Source: IPC, PRC and IEEE Spectrum
Georgia Institute of Technology
Sep 2014

Modern Packaging and its Relevance to System Integration & Miniaturization



Mini-computers introduced by Xerox PARC (1973)

Modern micro-computers from Commodore PET, Apple II and TRS-80 from Radio Shack (1977)

First portable computer – Osborne 1 (1981)

Modern mobile computers (mid 1990)

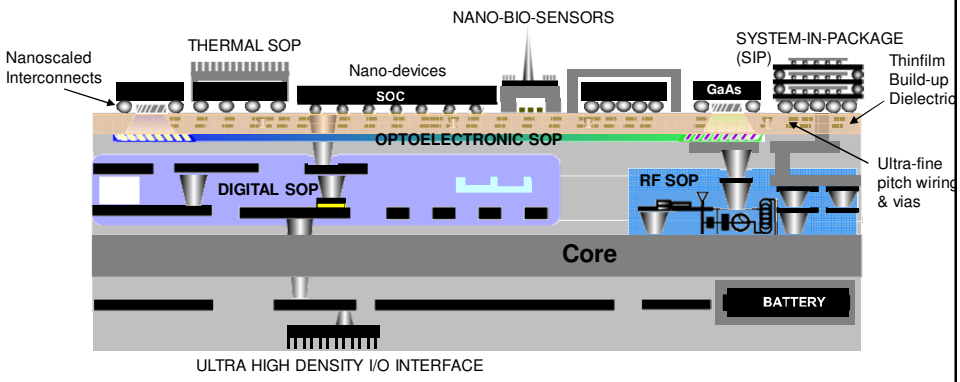
Notebooks (mid 2000)

- smaller battery, screen…

DynaTAC 8000x (1983)

Courtesy: Packaging Research Center, Georgia Tech

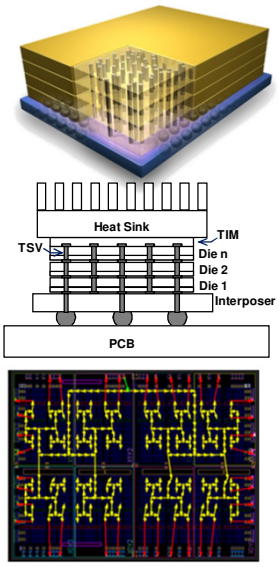
Integrated Systems

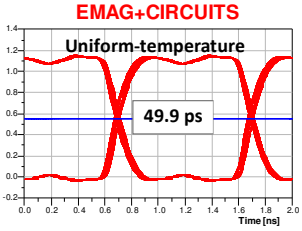


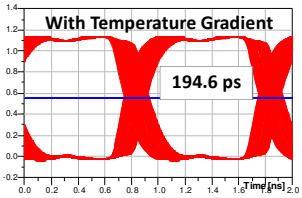
- ❑ Advanced Devices (FinFET, UTBFET, 2DFET …..)
- ❑ Ultra Low Energy Circuits
- ❑ Integrated Package with functional layers (RF, SENSORS, BATTERY …….)
- ❑ Highly Miniaturized "Internet of Things" System
- ❑ AT A REASONABLE COST!

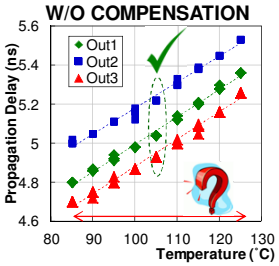
Courtesy: Prof. Rao Tummala, Packaging Research Center

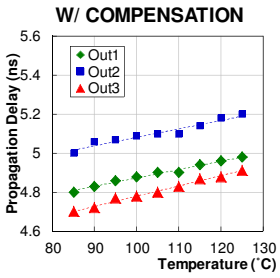
Computational Methods
The Multi-scale and Multi-physics Challenge



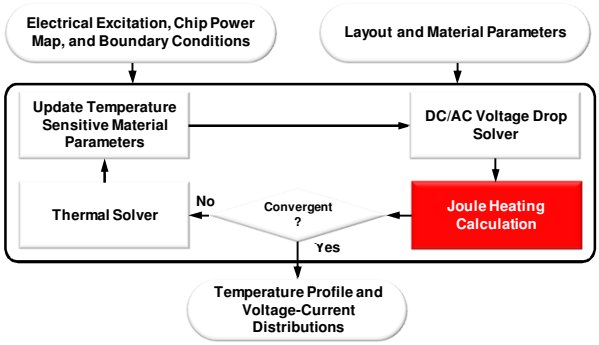


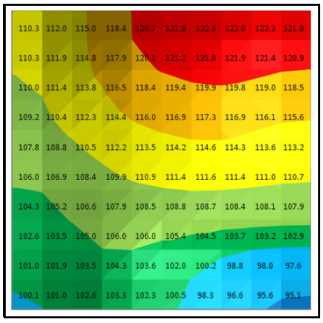






Computational Methods
The Multi-scale and Multi-physics Challenge (cont.)

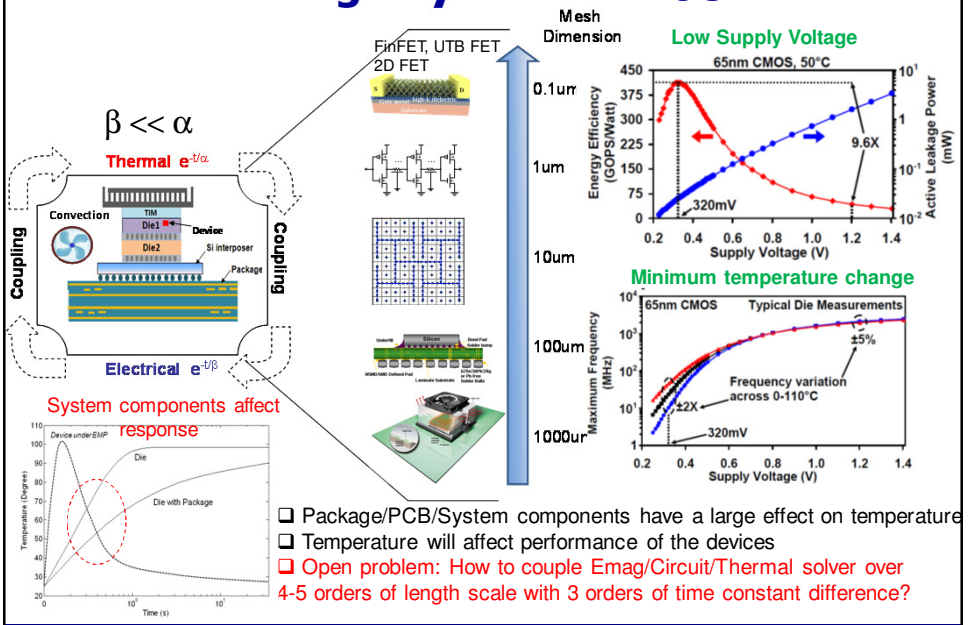




- ❑ Simultaneously model Electromagnetic, Thermal and Circuit Effects
- ❑ For systems containing advanced technologies:
  - ❑ Integrated Voltage Regulators
  - ❑ Embedded electronics
  - ❑ Microfluidics
  - ❑ Fine geometrical features ….

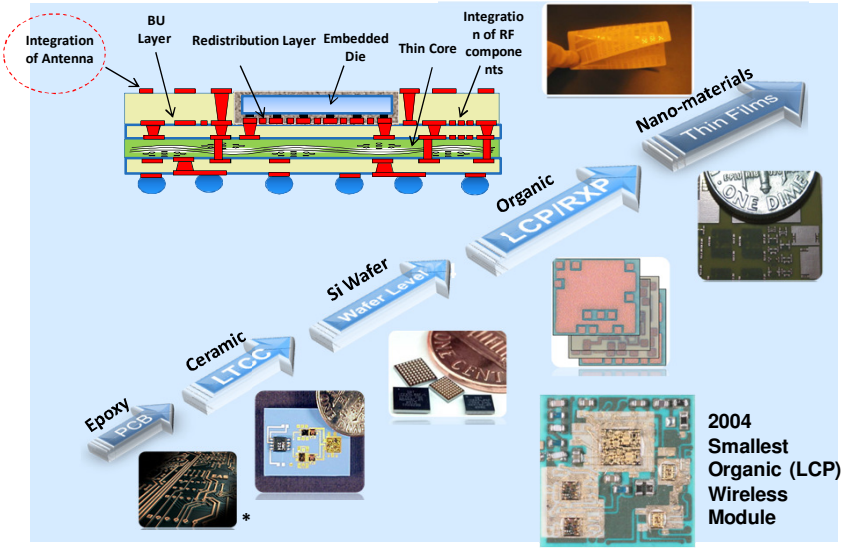
J. Xie, M. Swaminathan, "Electrical-thermal co-simulation of 3D integrated systems with micro-fluidic cooling and Joule heating effects," IEEE Trans. on CPMT, 2011.

Going Beyond Si CMOS



- ❑ Package/PCB/System components have a large effect on temperature
- ❑ Temperature will affect performance of the devices
- ❑ Open problem: How to couple Emag/Circuit/Thermal solver over 4-5 orders of length scale with 3 orders of time constant difference?

2. Wireless Integration

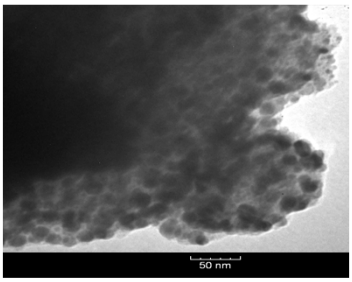


M. Swaminathan, V.Sundaram, J. Papapolymerou and R. Pulugurtha, "Polymers for RF Apps", IEEE Microwave Magazine, Dec 2011

Magneto-Dielectrics
Metal-Polymer Nanocomposites

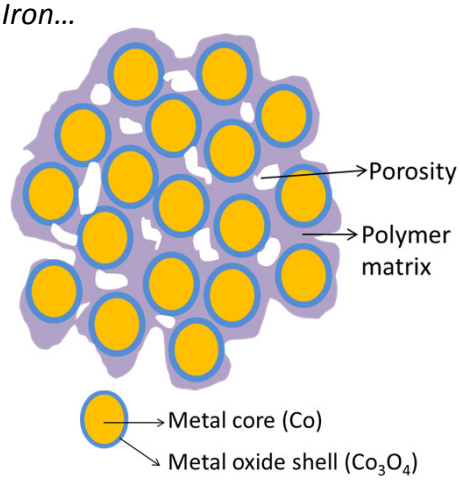
Material Choice

Metal Nanoparticles: *Cobalt,Nickel,Iron…*
Particle size: 10nm, 20nm,30nm….
Oxide Passivation
Polymer: *Epoxy, Fluoropolymer …*

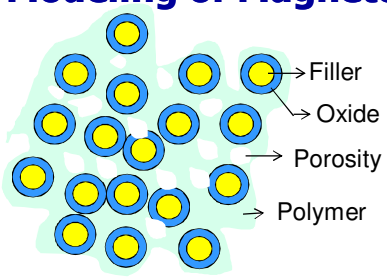


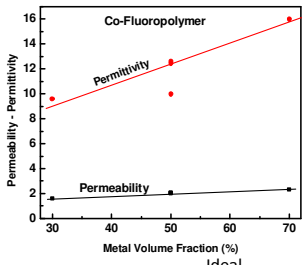
TEM image of Metal-Polymer matrix

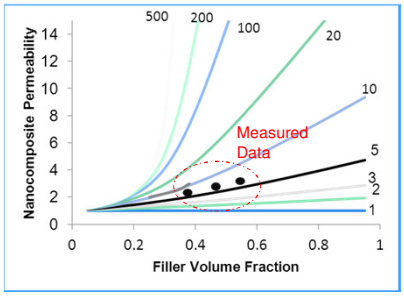
Composite Structure

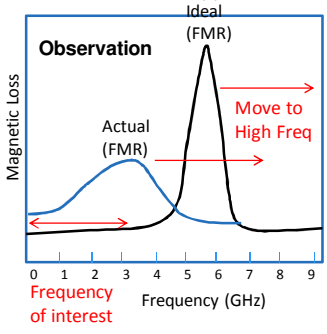


Modeling of Magneto-dielectric Nanoparticles



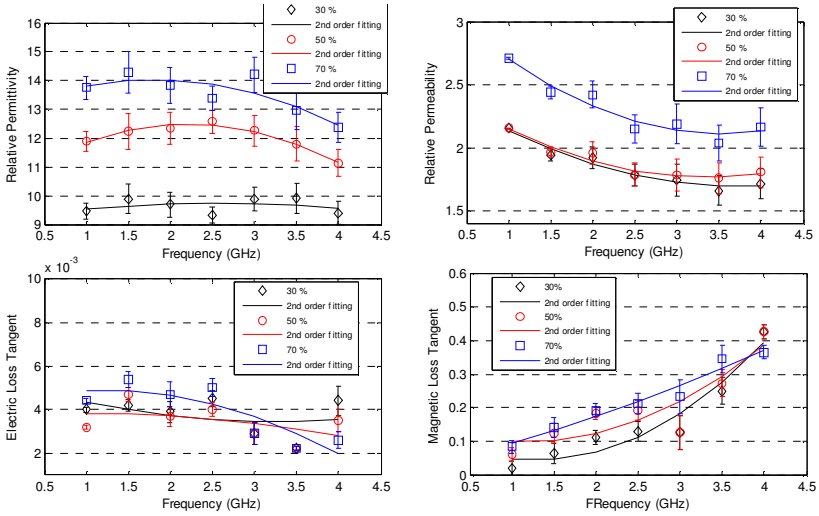






P. M. Raj et al, "Tunable and Miniaturized RF Components with Nanocomposite and Nanolayered Dielectrics", IEEE Nano2014

Measurement Results



✓ Best properties reported for Metal-Polymer Nanocomposites at RF Frequencies

Material Properties @ 1GHz (from measurements): ε_r=12; μ_r=2.2; tanδ_e=0.004; tanδ_m=0.06

U-Shaped Antenna

Material	FR4	MD	High K
	Er=4.3, Tande=0.025,	Er=11.9, Mr=2.15 Tande=0.0032, Tandm=0.0614	Er=21, Tande=0.0646,
Size	20 mm X 42 mm	14.8 mm x 20 mm	14.8 mm x 20 mm
BW (%)	19.6	9.96	8.63
Efficiency (%)	94.98	70.16	51.6

64.76% size reduction

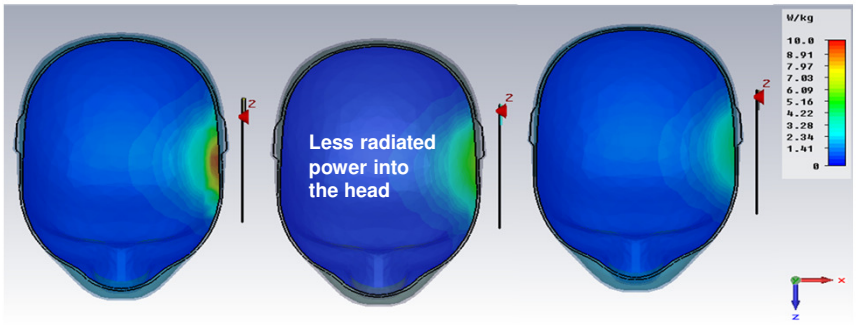
15.4% wider

36% higher

SAR @ 1GHz

1g Tissue
1W rms power

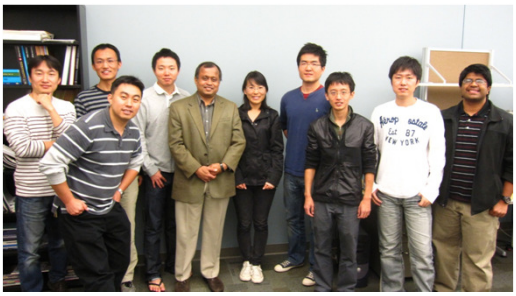
FR4 MD High K



✓ Good

Substrate	FR4	MD	High-K
SAR (W/Kg)	9.405	6.05	4.418

Thank you



NAMASTE

epsilonlab.ece.gatech.edu